VISUALIZATION MODEL FOR PRODUCT LIFECYCLE MANAGEMENT

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ABSTRACT: Product Lifecycle Management (PLM) demonstrated to be a good strategy for manufacturing enterprises. In spite of all the benefits it is not still clear how to implement it in industry. This article presents a visualization model of enterprise processes for a PLM system. It presents in a graphic way the main elements of a product lifecycle. The model identifies what is done (process, activities), when it is done (workflows), who does what (roles - skills) and how it can be done better (methods and tools). UML-RUP is used as representation technique. A case study, which analyzes the specification and inspection procedures of geometric tolerances according to the GPS approach, proves the convenience of this model for supporting PLM implementation.
KEYWORDS: PLM, UML, engineering processes, product design, GPS

INTRODUCTION

In the late 1980's emerged a model that took into account a general vision for managing and developing products and product related information from the initial idea to the disposal [1]. This model offered the possibility to keep track of the growing volumes of information generated in every phase of the product lifecycle. Nowadays this model is known as Product Lifecycle Management (PLM).

PLM is the activity of managing a company's products all the way across their lifecycles in the most effective way [2]. The heart of PLM is the product and for this reason PLM manages all the information about it including not only items, documents and Bill of Materials (BOM); but also analysis results, test specifications, environmental information, quality standards, engineering requirements, product changes, manufacturing procedures, product performance information, components' suppliers and so forth [1]. All the information is documented, managed and updated by persons from the organization that are following specific activities. PLM follows the product from "the cradle to the grave" a concept easy to understand but hard to implement.

The main difficulty in managing PLM model is due to the complexity of the activities taking place inside the processes. Chiabert et al. found that Small and Medium Enterprises (SME) hardly control the whole product lifecycle and rarely manage all the elements involved in PLM [3].

Stark [2] highlights that a feasibility study on PLM implementation needs to:

- Better understand the product lifecycle;
- Better understand the activities and processes across the lifecycle;
- Define the roles in the product lifecycle;
- Train people to work effectively in a lifecycle environment;
- Define information needs;
- Use a Product Data Management system effectively throughout the lifecycle.

This article presents a formal visualization model of enterprise processes for a PLM system which offers a graphic representation of the main elements of a product lifecycle. Information visualization is generally applied to the visual representation of large-scale collections of non-numerical information, such as files and lines of code in software systems [4]. A visual representation provides some means to see what lies within, determine the answer to a question, find relations, and perhaps apprehend things which could not be seen so readily in other forms [5].

A PLM system is composed of several components (product data, persons, activities, tasks, projects, workflows, etc.) that are interconnected and change during time. Understanding the relationship between these components becomes crucial so does the need of a visual representation.

The main objective of a visualization model is to make clear to everyone what happens in a particular process [2]. For this reason the visualization model looks forward to identify all the information needed to model a PLM framework.

VISUALIZATION MODEL

Over the years, industry has developed different display frames, methodological approaches and modeling languages in order to better understand complex organizational systems. Some of these tools are: Balanced scorecard, BPM (Business Process Model), EFQM (European Foundation for Quality Management), COBIT (Control Objectives for Information and related Technology), PMBOK (A guide to the Project Management Body of Knowledge), CMMI (Capability and Maturity Model Integrated), UML (Unified Model Language) and many others. Although all representations share a common goal, the specific objectives of each model change according to the nature of the sector they belong to and the characteristics of processes and activities involved.

With the aim of getting a general PLM framework (Fig. 1), this work establishes a classification of the main states of a product lifecycle. Inside each lifecycle state there are a series of processes with similar goals which are grouped in Process Areas (PA). A PA is a sequence of operations that can be depicted in a Workflow. In order to understand better every single operation of the workflow is necessary a Decomposition Diagram (DD). The DD is the partitioning of an operation into its component functions. The DD describes what is to be produced (Items), the necessary skills required (Skills), the responsible of the operation (Role) and the step-by-step explanation describing how specific development goals are to be achieved (Activities).

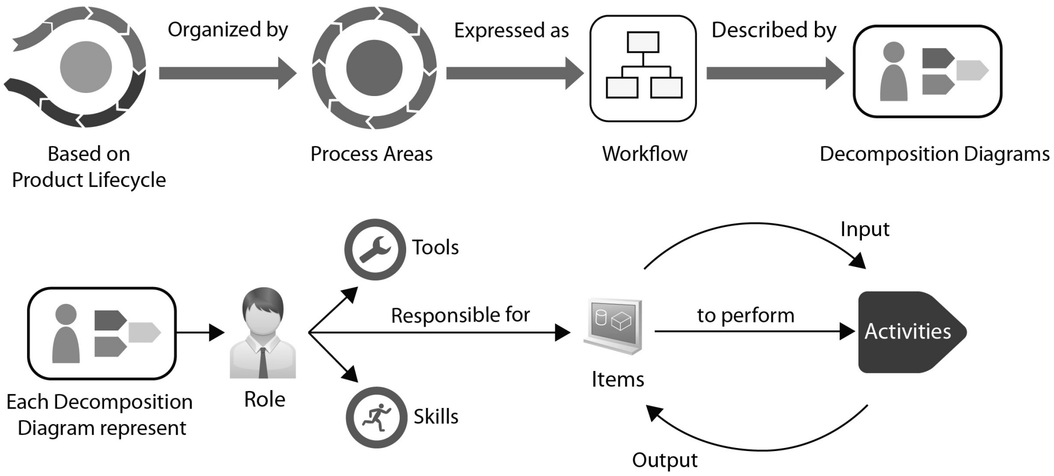


Figure 1 - Visualization Model Overview

Definitions of the lifecycle states and process areas were taken from different organizational fields: Project Management Model (PMM) [6] for the activities related to management, and CMMI [7] as reference for process areas. Visual representation follows the basis of:

- *UML diagrams for workflows;*
- *Rational Unified Process (RUP) for activities.*

Finally the information is settled in a display frame for an easy comprehension of all the information.

PRODUCT LIFECYLE

From the global resource viewpoint, there is an environmental product lifecycle in which a natural resource (e.g. an ore or oil) is extracted from the earth, the resource is processed, the resource is used in the manufacturing of the product, the product is used and when the product is no longer needed the resource/waste is managed - perhaps reused, recycled or disposed of [2]. As seen by a manufacturer of a product, there are six phases in a product's lifecycle: imagination; definition; realization; commercialize; support and disposal. From a PLM perspective, these six sequential phases, each phase ends by a major milestone; every single phase is essentially a span of time between two major milestones. At the end of a phase an assessment is performed to determine whether the objectives of the phase have been met. A satisfactory assessment allows the project to move to the next phase. The framework is built on the basis of product lifecycle phases (Fig. 2).

- *Imagination phase (concept): At the beginning of the project the company receives all information about the product from many sources: stakeholders, customers, marketing and production. Creativity workshops are held for the first product draft, the ideas are turned into sketches, drawings and diagrams explaining the product preliminaries.*
- *Definition phase (design): The sketches are transformed into technical drawings, modeling is done and product is defined (materials, dimensions and tolerances). A realistic product definition will be clear and verifiable (design shall meet user requirements); complete and accurate (design shall state user's real needs); and must be feasible [8].*

- *Realization phase (manufacturing): production is planned and pre-series and series of production are carried out based on the capability of the company. Suppliers' relationships are set. A proper design of packaging is made. This phase ends with the final assembly and storage.*
- *Marketing phase (distribution and sales): Marketing strategy is defined along with the transportation systems and distribution logistics to ensure that the product reaches customers' hands in the best conditions.*
- *Use-support phase (use and maintenance): From the user viewpoint this phase starts with the use of the product until the end of its useful life. From the business process perspective it is the beginning of the support & maintenance phase.*
- *Disposal phase: This phase is the end of product lifecycle and is open to three different scenarios: Recycle, Waste or reuse. Here is where the environmental impact of product through its lifecycle can be assess (resources consumed and emissions released) and the related effects on human health can be estimated [9].*

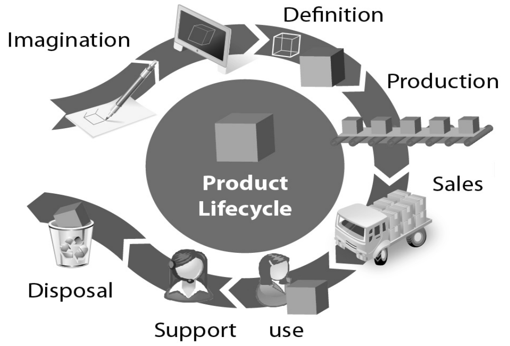


Figure 2 - Product Lifecycle Phases

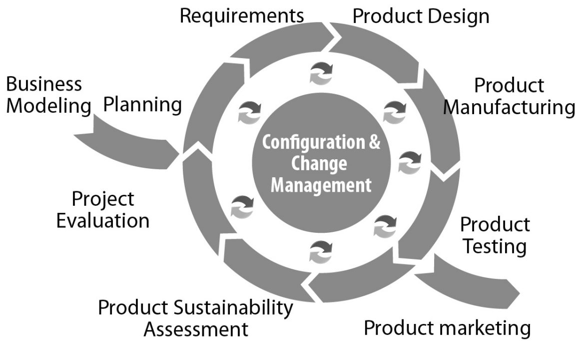


Figure 3 - Process Areas

PROCESS AREAS

A process area (Fig. 3) is a cluster of related practices in an area that, when implemented collectively, satisfies a set of goals considered important for making improvement in that area [7]. Every lifecycle phase represents different aspects of product lifecycle and contains different Process Areas (PA):

- *Imagination phase*
  - *PA Project Management: It is the discipline of planning, monitoring and controlling activities and resources consumed during the project.*
  - *PA Requirements Management: Its purpose is to handle the requirements of the project products and of product components. Therefore to identify inconsistencies between requirements, project plans and work products [9].*
  - *PA Conceptual design: It is used to generate ideas for product definition by applying creativity techniques. It is also given a preliminary description of product performance, functionality, materials, ergonomics, environmental impact, etc.*
- *Definition phase*
  - *PA Product Design: The objective is to define the product based on the conceptual design and product requirements. Sketches are transformed into more detailed drawings and 3D models with the support of computer aided design (CAD).*
  - *PA Configuration Management: Its purpose is to establish and maintain the integrity of work products using configuration identification, configuration control, configuration status accounting, and configuration audits [9]. Configuration management allows products to be customized according to customer wishes [7].*
  - *PA Prototyping: It ensures that the proposed design meets the requirements and parameters established before production. Prototypes (virtual and/or physical) can be tested under real conditions of use to analyze the product behavior.*
- *Realization*
  - *PA Logistics of suppliers: The process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods. It includes services and related information, from the point of origin to the point of consumption, for the purpose of conforming to customer requirements. It contains inbound, outbound, internal, and external movements [10].*
  - *PA Supplier Agreement Management (SAM): It wants to manage the acquisition of products from suppliers. SAM involves selection, establishing and maintaining of agreements, monitoring and evaluating of suppliers [7].*
  - *PA Manufacturing and assembly: The purpose of this process area is to produce parts and to assemble the product from the product components. It ensures that the product as a whole works properly and is responsible for the final deliver.*

- *PA Testing: The objective of this process area is to ensure product quality, to guarantee that the product meets client requirements (verification) and to demonstrate that a product or product component fulfills its intended use when placed in its intended environment (validation) [7].*

□ *Marketing*
- *PA Storage and distribution: its aim is to define the logistics of storage and distribution to sales points, the definition of physical product flow and the control of resources (staff, consumables, energy, etc.), necessary goods (equipment, systems, warehouses, infrastructure, etc.) and services (transport, etc).*
- *PA Marketing and sales: This area is responsible for marketing the product and putting it on the market in the shortest time possible, for defining advertising and promotion strategies. It is responsible for conducting surveys to hear customers' voice, for knowing the product perceived value and for estimating the price that the market is willing to pay for it.*

□ *Use-support phase*
- *PA Support and maintenance: it seeks to ensure optimal support for the user in order to have a satisfactory experience with the product. It offers use guidance and precautions as well as maintenance information.*

□ *Disposal*
- *A Disposal: according to the ISO 14000 standard, the three aspects to be consider in this phase are: the inventory of consumed energy, the inventory of emissions and the impact on environment and human health.*

MODEL FOUNDATIONS

A process is well described if it is clear who is doing what, how, and when. The Rational Unified Process (RUP) uses four primary modeling elements [11]:

□ *Workflows, the 'when'*
□ *Activities, the 'how'*
□ *Roles, the 'who'*
□ *Items1, the 'what'*

For the model presented here, workflow representation is based on UML as defined by the Object Management Group [12]. UML can be considered as a relevant and efficient notation enabling the modeling, specification, and implementation of PDM systems especially concerning the product structure and workflows [13].

Graphical representation of activities, roles and items is model through schemes based on Rational Unified Process (RUP) [14]. RUP is a comprehensive process framework that provides industry-tested practices for software and systems delivery and implementation and for effective project management. RUP has been applied successfully over the years in software industry. J. Martinez [15] found the following advantages:

□ *Product Development time and cost reduction;*
□ *Failure diminishing (less non-conform products);*
□ *Better document control.*

RUP has been applied successfully in software industry that leads us to think that RUP can also be implemented effectively to represent processes in the manufacturing industry. PLM manages Configuration Management a discipline that has also its origins in the software and that nowadays is topical in industry.

Workflow

A workflow is a sequence of activities that produces a result of observable value [11]. The UML representation offers a unified standard suitable for complex processes. Fig. 4 shows an example of "GPS (Geometrical Product Specifications and Verification) Workflow". UML is suitable for parallel activities, those activities cannot be represented in the same diagram with a classic flowchart.

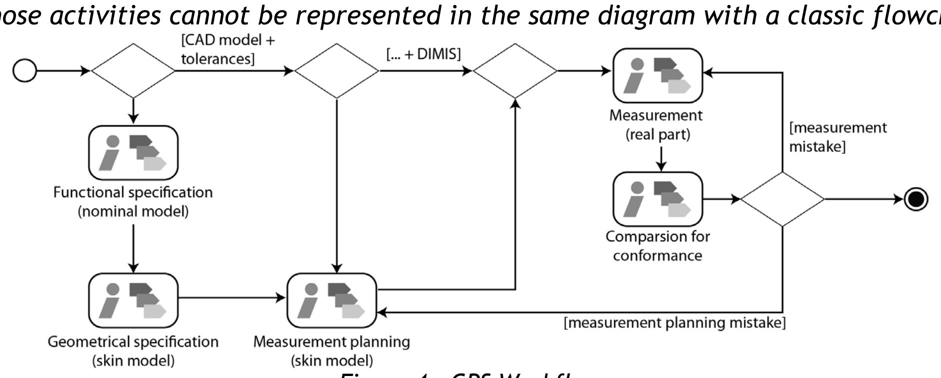


Figure 4 - GPS Workflow

[1] *RUP definition for the "what" are called Artifacts. Artifacts are tangible products result or output of every activity. In terms of PLM this is called Items.*

Decomposition diagram (DD)

The DD show more detailed components of operations. Workflow operations are broken down into activities that are easier to conceive and understand. The DD describes, in a graphic way, the interactions between activities, roles, items, tools and skills. Activities are performed by a single role of the organization which should have a range of skills and knowledge and may need some tools. The result of the activities is work products (items) that must be controlled by PLM software. DD permit system administrators, project managers and users to determine if all required information will be accounted for in the system. Fig. 5 highlights the main elements of a DD.

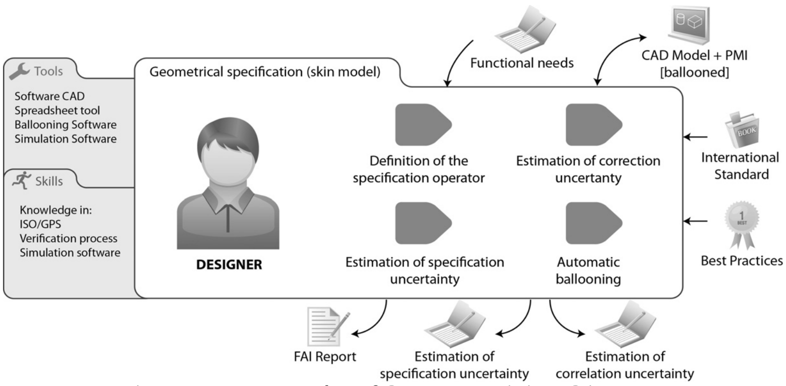


Figure 5 - Example of Decomposition Diagram

Activities

Activities can be subdivided in a series of smaller and manageable tasks. A single individual will be responsible of each task. Each activity has an Activity Sheet where is defined: Objective; Tasks; Input/Output items; Roles; Next/previous activity; Tools and Workflow details.

Roles

A role is not necessarily a single person: it can be a workgroup that is responsible of an activity. A Role diagram (Fig. 6) shows all activities done and the items produced by the role during the whole product lifecycle and not only for a single activity (which is the case of the DD).

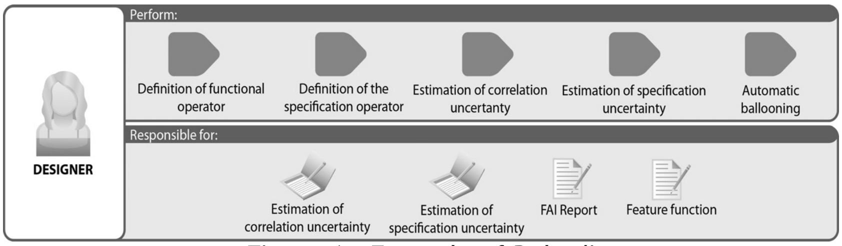


Figure 6 - Example of Role diagram

Item

Items are work products obtained after an activity is completed. An item can be a document, a 3D model, a standard, a Gantt chart, a guideline, document plans, etc. Each item has an Item Sheet containing the following information: Description; Role owner; Enclosed in; Template; Other information; Input to activity; Output from activity. The visualization model allows also the representation of the Item Network Overview (Fig. 7) where the relationships and evolutions between Items are shown all along product lifecycle.

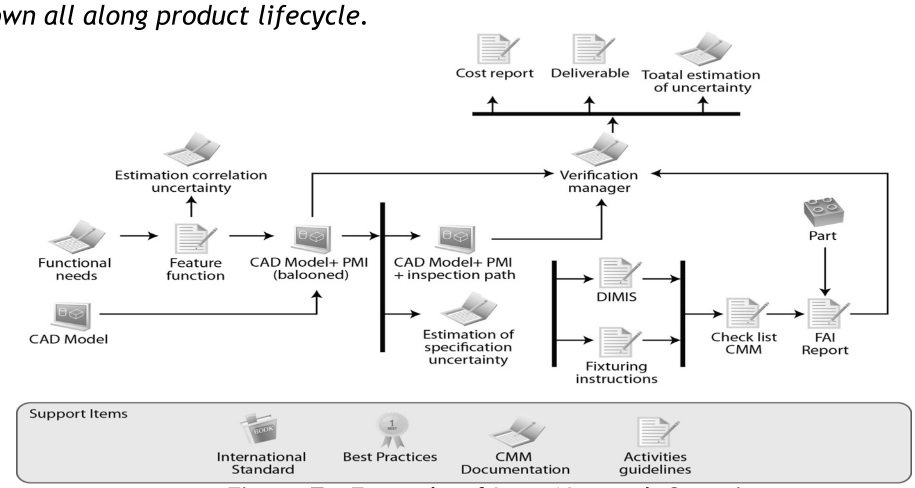


Figure 7 - Example of Item Network Overview

Tools and Skills

Once tasks have been clarified, people can be assigned to carry them out as a function of their skills, knowledge and competence [2]. Companies can identify the needs of training for every role participating in the product lifecycle. Roles executing activities must need a set of Tools that automates the application of that activity. These tools can be specialized software; a marketing technique; a particular application developed by the company; etc.

PLM INTEGRATION

Once the product lifecycle is understood, activities and tasks are defined, responsibilities are established and information needs are identified; then implementation of product lifecycle in PLM or

PDM software can be easily carried out. PDM systems aim at managing and storing the product data together with the information generated along its entire lifecycle[16]. PDM software needs:

- *Organization structure (Roles).*
- *Activities sequence (Workflow and decomposition diagrams).*
- *Documentation to be administrated by the system (items).*

With the implementation of this framework the adaptation is done in the direction of the software to product lifecycle and not the opposite. The framework also permits the establishment of Configuration Management process. By the graphic representation of Group Activities, Roles and items it is possible to determine the item owner and the effects of changes and revisions of the released versions.

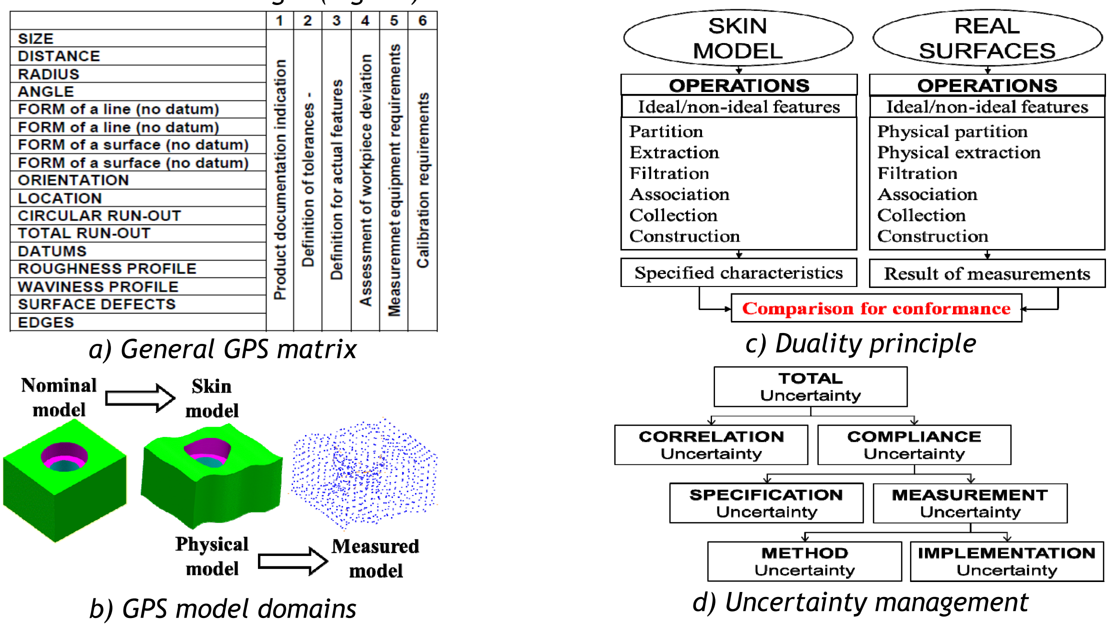
VALIDATION

The visualization model is currently being tested within the project GREAT 2020-Ecoprolab3. This project wants to apply the specification and inspection procedures introduced by ISO under the Geometrical Product Specification and Verification (GPS) program.

The goal of GPS program is the definition of a new language for the geometrical description of manufactured workpiece. In spite of the large amount of work and study devoted to the realization of a complete, coherent and reliable solution for the control of product shape, such result is not caught yet. Along the product lifecycle (design, manufacturing and verification phases) there are several gaps which prevent a successful management of geometrical information. Since the last decade of the last century a progressive reduction of dimensional and geometrical tolerances requested in manufacturing process proved the existence of a problem in the description of product shape.

The GPS program aims to enlarge the product tolerances by means of a better description and management of tolerances along the product lifecycle. The Masterplan of GPS program [17] collects most of the fundamental concepts:

- *the General GPS matrix (Fig. 8a) represents the tolerances available in mechanical design; the rows contain the different tolerance types and the columns contains the six main steps needed in tolerance definition. Each cell defines a concept/activity involved in tolerance management and should be covered by one and only one ISO standard in the GPS program [17];*
- *the GPS approach recognizes the existence of three different environments in product shape definition: the nominal model which is composed of ideal surfaces and is illustrated on drawings [18]; the skin model which takes into account the geometrical errors described by tolerance callouts; the physical model resulting from the application of a measurement process on the physical workpiece (Fig. 8b);*
- *there is a natural correspondence between the activities developed on the skin model by the designer and the activities carried out by the metrologist on the physical workpiece [18,19]. Such duality principle allows for the comparison of requirements defined in the specification phase and the measurements carried out in the verification phase (Fig. 8c);*
- *all the activities developed for the control of product shape in the specification and verification phases are defined by operators which are composed of operations and are affected by uncertainty [19]. A good geometrical control provides the lower total uncertainty given the available economical budget (Fig. 8d).*



a) General GPS matrix

b) GPS model domains

c) Duality principle

d) Uncertainty management

Figure 8 - Main concepts in GPS project

In the modern industrial environment, the specification process is to "translate the design intent into requirement(s) for specific GPS characteristics" according to ISO/TS 17450-2 [19]. Currently, specification inadequacy is the Achilles heel for many of today's technologically advanced companies [20]. Specifications errors are propagated to other views of the product (product planning, manufacturing, quality control and inspection) [21]. Therefore, GPS provides a precise expression of functional requirements, complete specifications and an integrated verification. Nevertheless, the standard by itself is of little use, its utility depends on industrial adoption [22].

GPS standards are available in ISO since 1996 but their application in industry is limited to specific cases, most of them are case studies developed by research centers in order to evaluate the advantages of GPS approach. Some GPS concepts are now part of the cultural background of many designers, engineers and metrologists, but there is no evidence in the scientific literature that a complete GPS compliant system has been applied in any enterprise.

The GPS approach appears to be more complex than similar methods currently used in industry, as Geometric Dimensioning and Tolerancing (GD&T), but this is not really true. The GPS project allows for a more precise and articulated definition of geometrical control. It provides the designer with a more powerful tool in the development of sophisticated geometrical controls which protect relevant product functions (aerospace engine applications, automotive safety devices, etc.…). Nevertheless the GPS approach promotes a simplification of information sharing along the product lifecycle and supports the development of concurrent engineering methods.

Undoubtedly, GPS-based activities encompass the production of a great amount of information shared by different roles within the organization. Traditionally, this information is stored and managed in the form of files that anyone can change and share by e-mail. The consequences of this practice are:

- *A great confusion among project participants;*
- *Loss of information;*
- *Errors and rework.*

The PLM paradigm provides a solution for information management issues and the development of a PLM tool which supports the development of geometrical controls according to the GPS approach seems a promising solution.

The aim of the job carried out in the framework of GREAT 2020-Ecoprolab3 project is to transfer the concepts indicated by GPS to the industry by means of a PLM based protocol. For this purpose, it was necessary to examine "product definition and verification" processes of project partners and define a general model able to describe all the processes used by project partners. The result of such modeling activity, based on UML-RUP, consists of a Visualization model containing the workflow of activities (Fig. 4); 5 decomposition diagrams of the workflow (i.e. Fig. 5); 3 roles diagram (i.e. Fig. 6); 15 activity sheets; and 1 item network overview (Fig. 7).

The PLM protocol under development will implement the whole GPS chain for one type of tolerance in order to support the development of product geometrical control along the phases of design and verification. It will drive the actions and the choices of designers, engineers and metrologists providing the right information to the right people at the right time.

Until now, the Visualization Model has clarified the activities and tasks that every role in the project has to perform in order to correctly and completely define product specifications and verification. Moreover, it shows the evolution of data along the project and the interaction between roles. The model is being tested in two PDM software in order to assess model deployment. Final conclusions of model validation are expected in May 2012.

According to the experience the authors are developing in the framework of GREAT 2020-Ecoprolab3 project, the Visualization Model is a powerful tool for information management. The analysis of partners' product development processes is a complex task where the Visualization model provides a better understanding of processes and a clarification of the embedded hierarchy in the people roles.

Moreover, the comprehension of GPS concepts is efficiently supported by the detailed description of workflows, activities, data, roles provided by the Visualization model.

Finally, the Visualization model simplifies the development of PLM applications to support people involved in the product development process. It reduces the gap between the tasks supported by PLM software and the real activities managed by designers, engineers and metrologists.

CONCLUSIONS

PLM is a complex system difficult to implement and understand, especially for small and medium enterprises that usually do not have sufficient maturity to define processes. Nevertheless, PLM is the only solution when large amount of complex data must be managed within industrial activities.

Visualization Models are an adequate mechanism for the representation of business processes, facilitating the implementation of models such as PLM. Through visual representation of processes

(UML and RUP) it is possible to identify what is done, when it is done, by whom and how it could be done better.

GPS project is a new approach to the geometrical control of products' shape. According to the objectives of ISO/TC213 Technical committee, the GPS project should provide a complete set of standards to address the control of manufacturing errors by means of dimensional and geometrical tolerances.

Authors are currently testing a Visualization Model framework for the management of Geometrical Product Specifications activities within a large aerospace company. Preliminary results are encouraging, but the final conclusions are expected in May 2012.

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